Cornell Linear Collider Detector Research

Cornell Interests:

The Cornell group proposes to contribute
to development of charged particle tracking
for the the N. American “Large Detector” design.

Detector Development (in collaboration with Purdue University)

Event Reconstruction, Pattern Recognition

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& students

Charged Particle Tracking at the Linear Collider

The challenges:

Momentum resolution

$\delta p_t/p_t = 4 \times 10^{-5}$/Gev …

(can be achieved with)

2 meter outer radius detector, 3 Tesla

120 µm spatial resolution

10 µm intermediate detector at R=0.4 m

10 µm vertex detector

Track density, Reconstruction efficiency

100 tracks/steradian …

"full" efficiency for "energy flow"

5% occupancy goal requires

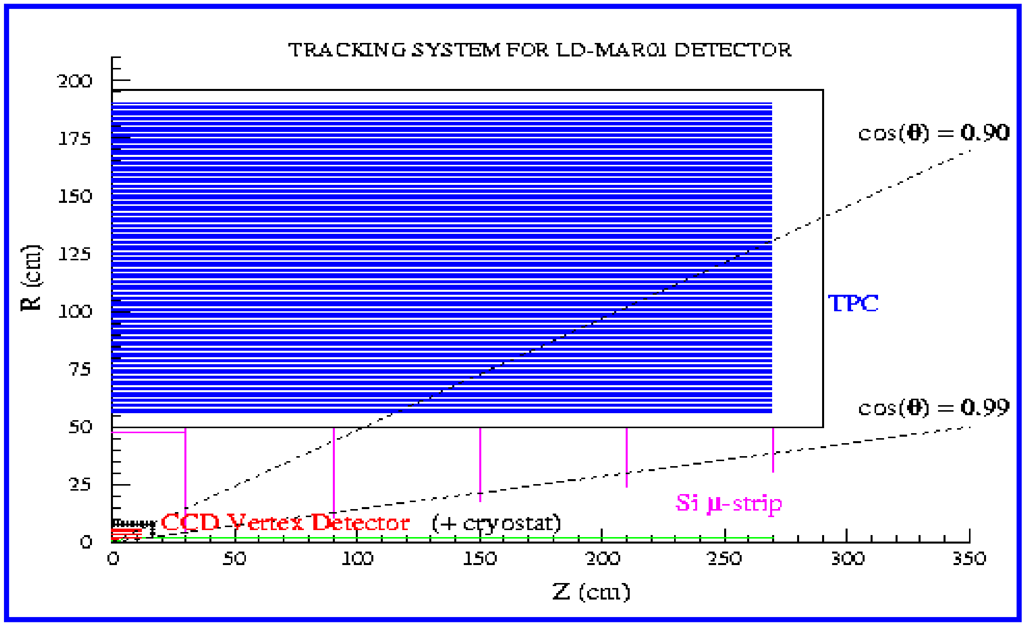
1/2000 ster. segmentation

example: 1.25cm(r-ϕ) x 1cm(z) at 50cm(R)

Noise density

" 1% by volume "

requires more segmentation



Schematic quarter-section of the
N. American "Large Detector"
including a 2 m radius Time Projection Chamber.

Goals of Cornell Tracking R&D

A TPC, using a GEM or MicroMegas amplification read-out, promises to provide the segmentation and spatial resolution required to meet the physics goals and the operating conditions. *Significant development and operating experience is required before a design can be finalized.*

Cornell is planning a two-part program
in contributing to the development of a TPC for the Linear Collider.

Detector Development Program (with Purdue University):

Optimize TPC read-outs in **prototype test chambers** for
track-track separation and **position resolution.**

Studies would include both
traditional anode-wire-amplification readouts and
GEM and MicroMegas amplification readouts

Coordinated with the development programs in Canada and Europe.

Event Reconstruction Program:

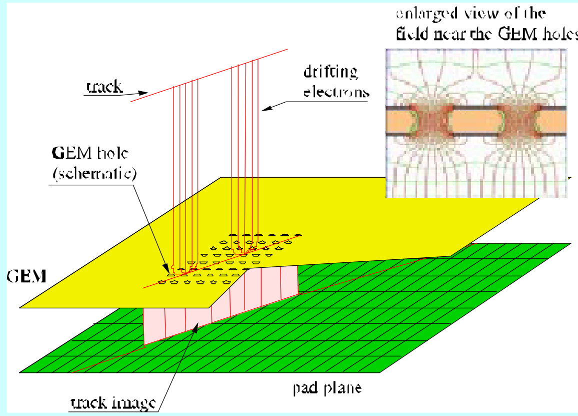
Quantify the performance of full-size tracking devices in terms of
track-reconstruction efficiency and **track-parameter resolution**,

with respect to the
device properties that can be determined from the prototype work.

Detector Development, issues

GEM/MicroMegas amplification read-outs are expected
to have advantages over traditional anode-amplification read-outs.
Signals are due to electron transport, rather than induction;
the signal width is narrow, typically 1 mm or less.
ExB effects, present with anode-wire-amplification, are minimized;
an improvement in resolution is expected.

While the electron transport signal is fundamentally narrower than the induction signal, Sufficient resolution, in a TPC, has not been demonstrated.



GEM readout: amplification is localized in the GEM holes. Signal is due to electron transport.

Resolution:

GEM/MicroMegas signals may be small compared to the pad width. ⇨ minimal charge sharing

e.g. 5mm (ϕ) x 1cm (r) pads (500 thousand pads)

The resolution, without charge sharing, is 1.4mm (require < 120 μm).

e.g. 1mm (ϕ) x 1cm (r) pads (2.4 million pads !) ⇨ provides charge sharing

The resolution may be sufficient but number of channels is prohibitive.

Tracks crossing cell ϕ-boundaries + finite ionization leads to distortion of charge sharing.

Ion Feedback:

GEM/MicroMegas promise to provide natural ion feedback suppression.
The need for a gating grid (as used in traditional anode-amplification readout-out) must be evaluated.

Electric Field Break-down:

GEM/MicroMegas are relatively new devices. More studies are required.

Detector Development, hardware

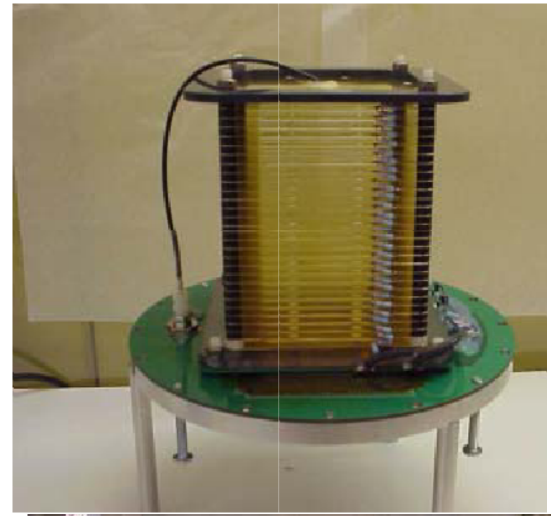
Components

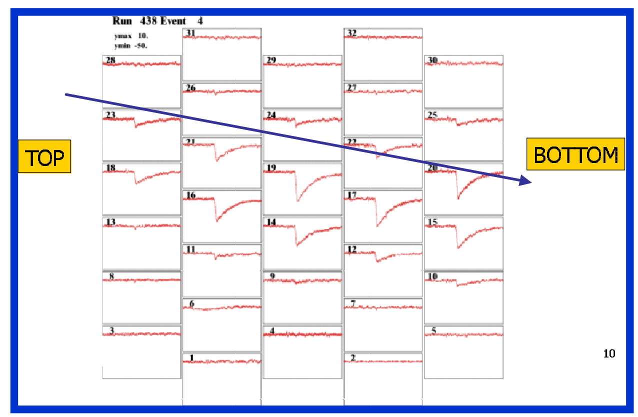
TPC to be built by Cornell (figure shows a Carleton device)
~20 cm diameter x 50 cm (z) device
to accept interchangeable readout planes

read-out planes start with 32 channel, later 250
interchangeable modules,
→ traditional wire amplification read-out modules
(for baseline and development studies)
to be built by Cornell
→ various GEM and/or MicroMegas read-out modules
to be built by Purdue
(figure: Purdue double GEM device for aging studies)

drift chambers for track definition, to be built by Cornell

data acquisition system funding requested through UCLC
256 channel FADC system
100 Mhz (with v=50mm/μs, provides 0.5 mm sampling)
sufficient for resolution and inductive noise studies
(figure shows a Carleton event, time dependence on 32 pads)





TPC photograph and read-out display figure stolen from Dean Karlen
Double GEM read-out figure stolen from Ian Shipsey

Currently Active/Funded R&D
TPC with GEM/MicroMEGAS

Carleton	TPC with GEM readout
	X-ray point resolution, induction resolution, track resolution
	Pad shape, signal shaping
Saclay	TPC with MicroMegas readout
	planned (January) 0.45 m diameter TPC in 2 Tesla field
Desy	TPC with GEM readout
	1 m drift TPC: amplification, track resolution
	small TPC: ion feedback
	planned (January) up to 5 Tesla field

Detector Development, Cornell/Purdue Program

Systematic study **spatial resolution** and **signal width** using
GEM/MicroMegas TPC readout devices

amplification device,
details of spacings and gain,
pad size and shape
gas
applied signal isolation/spreading (Signal may require spreading in ϕ and isolation in R.)

Signal spreading must be optimized for segmentation and resolution.

Spatial resolution and signal width studies using
traditional anode-wire-amplification read-out devices
Investigate a readout using smaller wire spacing to reduce the **ExB** effects.

Ion Feedback measurements
Instrument the high voltage plane, or an intermediate grid.

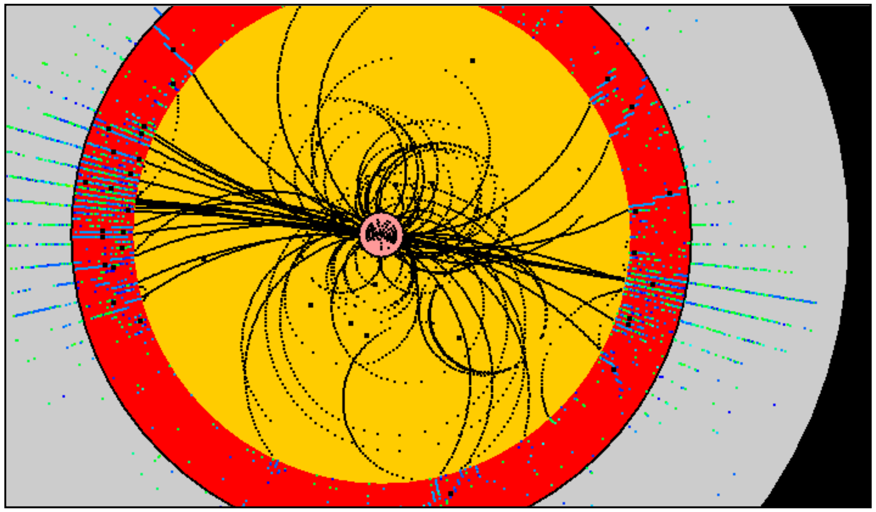
Tracking studies in a **high radiation environment**
Studies of signal distortion and electric-field break-down.

Tracking studies in a **magnetic field**
Cornell has the expertise and utilities to build and operate a superconducting test magnet.

Charged Track Pattern Recognition at the Linear Collider

Hardware studies of tracking detectors, in controlled, low multiplicity conditions, provide **spatial resolution** and signal width characteristics (**track separation at the level of a single layer**).

Detector performance, in terms of **track-parameter resolution** and **track-reconstruction efficiency** in the complex event environment expected at the linear collider, must be inferred through **simulation**.
(*Efficiency can only be defined with respect to satisfying a condition, possibly track-parameter matching.*)



Simulations can include most of the effects that distort the detector signals:
noise (electronic, radiation)
signal overlap,
non-Gaussian tails of the detector response functions.

While simulated events can be made to closely match the real data, the ability to provide relevant predictions of tracking resolutions and efficiencies requires a **mature pattern recognition algorithm**.

Application of CLEO III Track Finding to a TPC

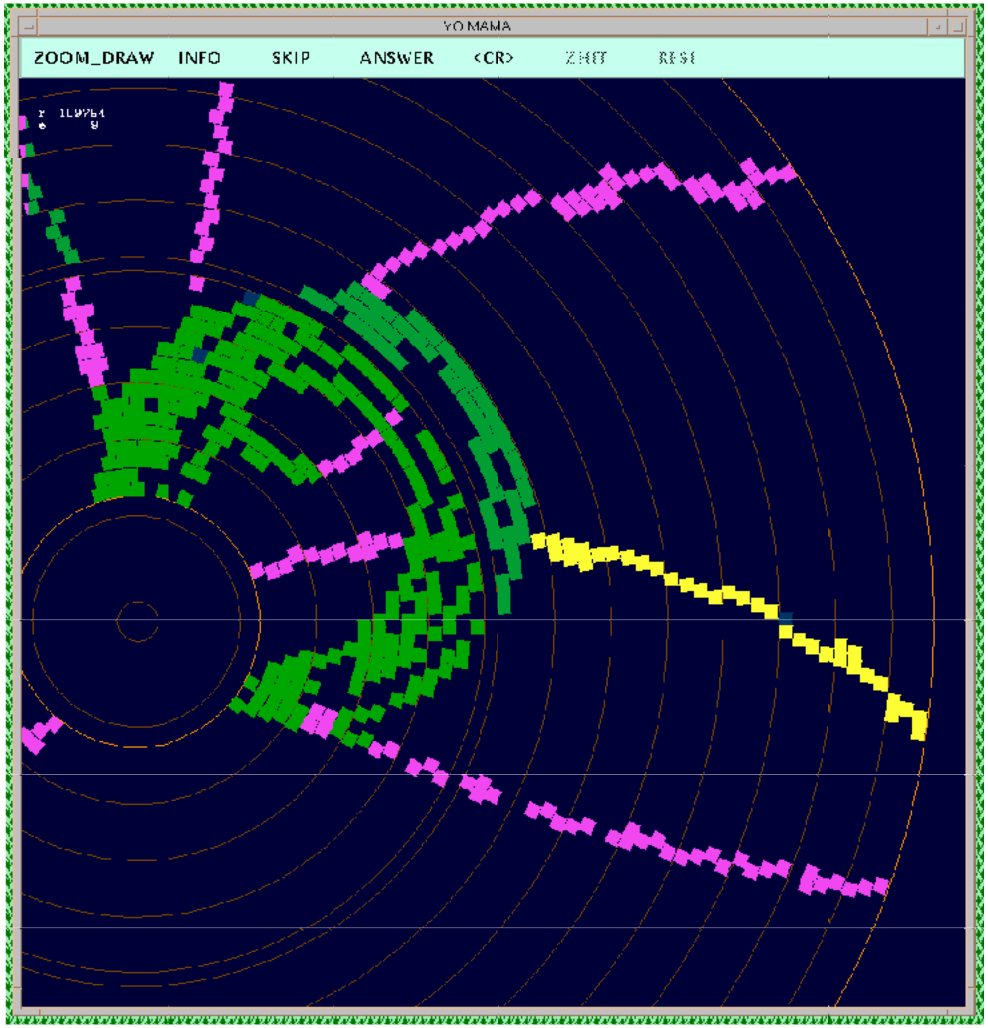
CLEO III track finding uses
cell level information in the initial phase,
does not depend on intrinsic device resolution,
is ideal for high (radial) density, low precision,
information.

CLEO III track finding was developed for a small-cell drift chamber but is applicable to any detector with similar cell-level information.

The goal of the initial phase is to
find segments that one would see by eye,
isolated anywhere in the chamber,
in contrast to algorithms seeded by arcs
defined by widely spaced (in radius) sets of hits.

A TPC is a 3-dimensional device. However, after clustering of the pad signals in r-ϕ, and assigning the cluster position to the closest pad center, projected TPC cell-level information is similar to that of a small-cell drift chamber.

This algorithm is readily applicable to a TPC.
(Coarse Z information can be used to
reduce track and noise density
that is projected onto the 2-D view.)



Why use the CLEO III Track Finding ???

There are **many philosophies** of how to do charged track pattern recognition:

- seeding with arcs defined by widely spaced hits,
- look-up tables,
- matching strings of well-defined arcs, “link-tree”
- this one, seeded by segments found at the cell level.

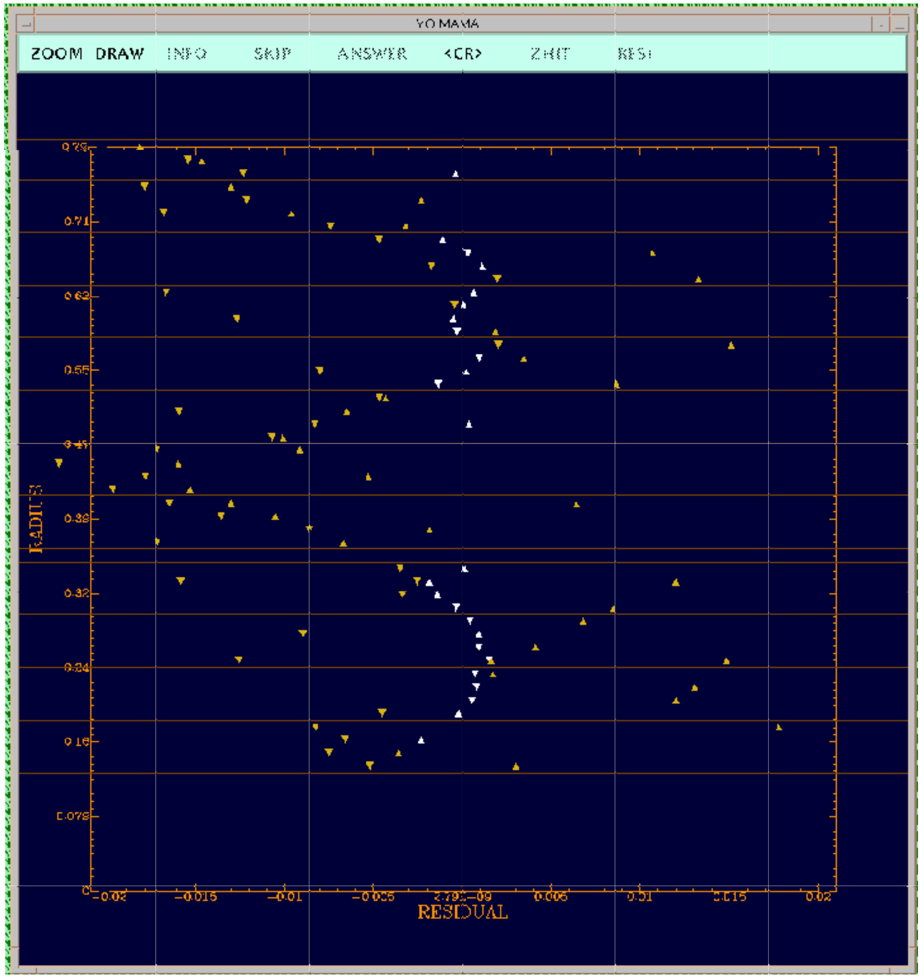
Any can be made to work; each has proponents.

However,
an important feature of CLEO III track finding is the **diagnostics package** accessing information on the conditions encountered & decisions made in selecting track candidates at **intermediate steps** in the algorithm.

It is used for **program development** and provides the ability to **visually diagnose problems and pathologies.**

The diagnostics package provides an environment to **rapidly optimize** the algorithm for the application.

Displays of the **residuals** and **z-projection** are used for diagnostics and development of the later phases.



Residuals: example shows the diagnosis of problems in treating decays-in-flight.

Application to a TPC, a "TPC event"

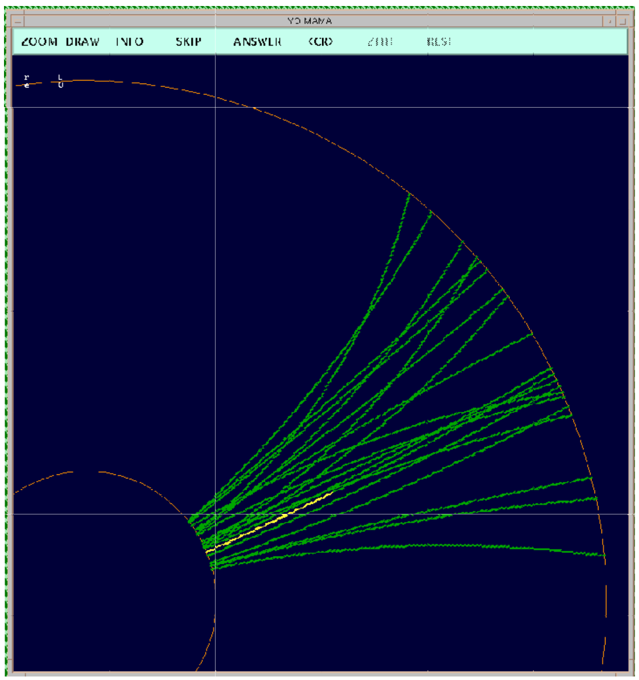
TPC and small cell drift chamber information are similar.

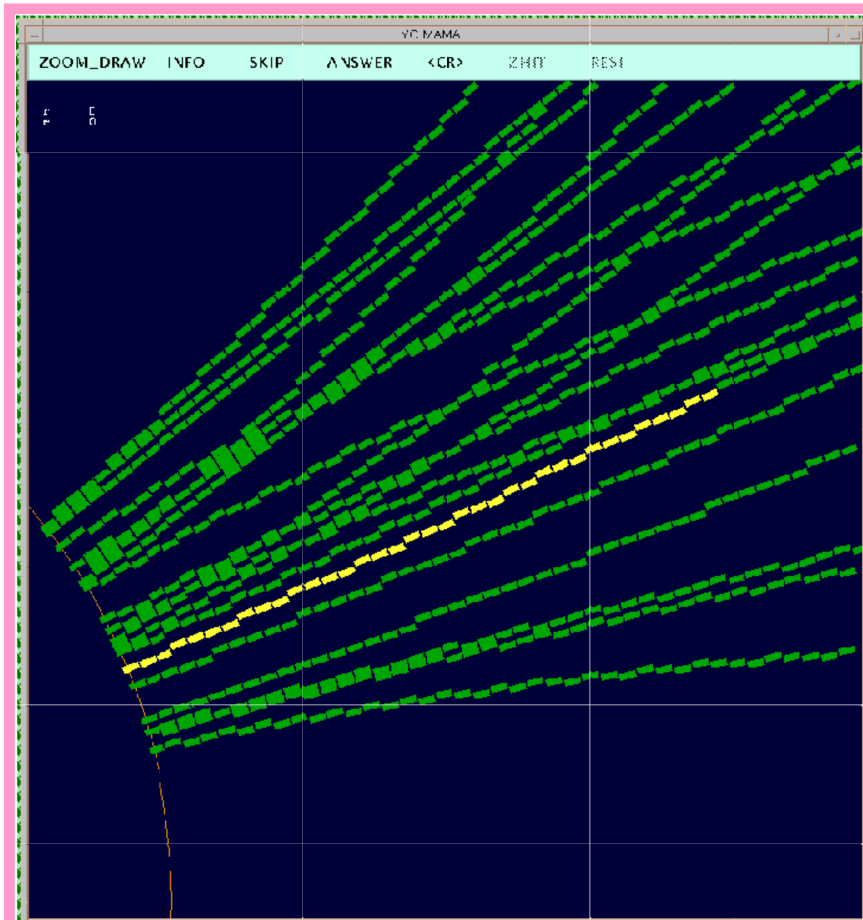
Differences in the way z-information is derived appear as details in the pattern recognition fitting procedures.

demonstration with an idealized detector:

100 layers, 2m o.r.   5mm x 15mm cells
single pad "hits", no clustering, no noise,
no Z clustering, only 1 hit/cell

Simulate 20 tracks in a jet, 100 tracks/steradian.

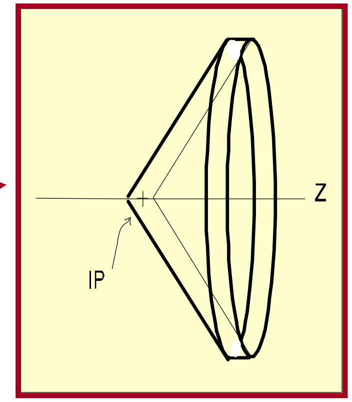




No changes to the basic pattern recognition.
No Z information is used, yet

TPC event using z-projection filter

20 track jet; track density increased to 200 tracks/steradian.
Hits are pre-selected to come from a z-projection cone.

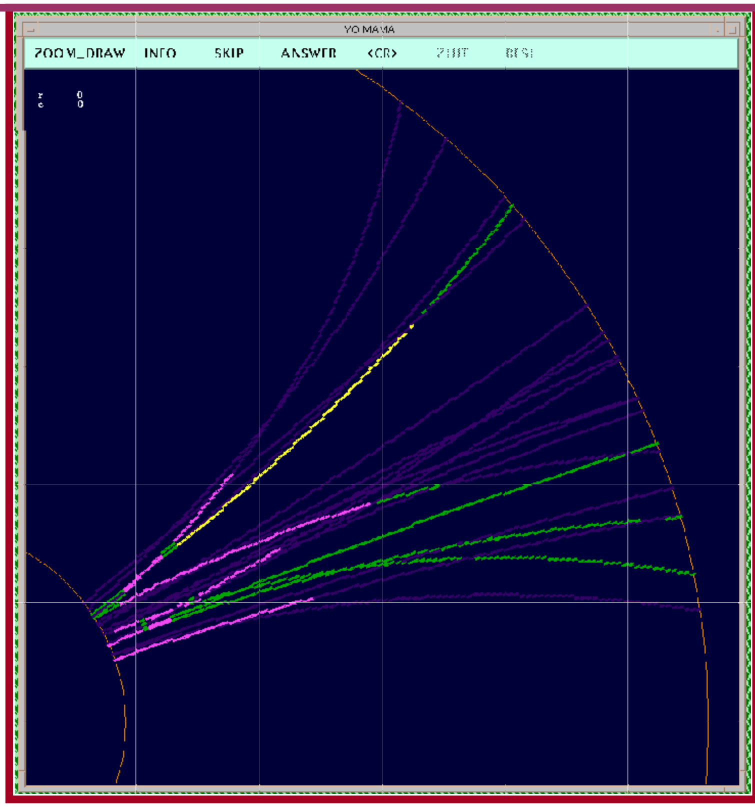


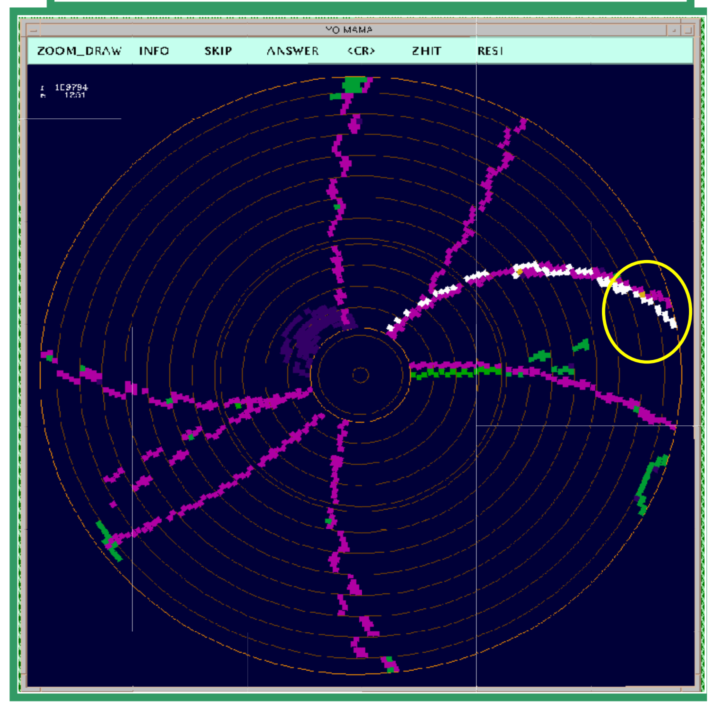
Yellow indicates current track, Magenta, previous found segments
Green, valid hits for pattern rec., Purple, invalid, out-of-time.

Tracks can be resolved.
Short segment are ignored; they will be resolved in another projection.

Scanning through the z-projection roads provides events with complications similar to those observed in CLEO III.

CLEO III track finding,
using fitted track segments
in **self selected isolated regions,**
is successful in extending tracks
into **complicated noisy regions.**





Application of CLEO III Track Finding to a TPC, Plan

First Year

- **Encapsulate** the existing code for compatibility with the established "LCD" event simulation program at SLAC.

  The current LCD simulation provides only points in 3-space indicating the crossings of the generated tracks with idealized detector elements

- To the event description, add **read-out** **pad structure** with **signal spreading** and **resolution**, **noise**, **signal merging**.
- To the pattern recognition algorithm, add **clustering** in r-ϕ and Z
- Optimize the method of selecting/scanning the **Z-projection roads**.
- Add **TPC detector specific information** to the later stage pattern recognition.

Provide preliminary analysis of track separation and pattern recognition efficiency with respect to detector resolution and segmentation (r-ϕ and Z), track density, and noise level required to to set goals for the (world) hardware development.

Longer range

- Convert all code to be compatible with an **existing Linear Collider detector simulation**.
- Add **read-out specific** (anode wire vs. GEM/MicroMegas) signal spreading characteristics
- Build **robustness** into the algorithm against signal pathologies through **tuning** with the aid of the graphical diagnostics.

Fully integrate the pattern recognition into the existing (and evolving) Linear Collider full-detector simulation.

Provide detailed, robust, analysis of track separation and pattern recognition efficiency.